REGIONAL VARIATIONS IN THE SHEAR-WAVE Q STRUCTURE OF SOUTHERN ASIA

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ABSTRACT

Models of shear-wave Q (Q_μ) have been obtained for a broad region of southern Asia that stretches across most of China and Mongolia. The models were derived using two methods. The first method inverts attenuation coefficients of the fundamental Rayleigh mode obtained using a standard two-station technique and the second method matches theoretical amplitude spectra for fundamental- and higher-mode Rayleigh waves computed for assumed velocity and Q models, and earthquakes with known source depths and focal mechanisms, to observed spectra. The latter method provides much better regional coverage than the first and allows us to map lateral variations of shear-wave Q at various levels in the crust and uppermost mantle.

For the single-station, multi-mode method, we assumed an Earth model consisting of three Q_μ layers, layer 1 being 10 km, layer 2 being 20 km, and layer 3 being 30 km thick. From data collected to date, Q_μ in layer 1 achieves lowest values (about 40) in portions of western China, including part of the Tibetan Plateau, and attains highest values in regions of southeastern China (as high as 220) and in westernmost China near the Tarim Basin. Layer 2 displays lowest Q_μ values in the southeastern Tibetan Plateau (as low as 60) and highest values in a small part of south-central China (180 or more), along the coastal region of eastern China (up to 140), and in a north-south trending band through central China (120-140). Although the resolution of crustal variations is poorer for layer 3 than for the shallower layers, some variations can be detected. The Q_μ map for that layer displays maxima under north-central China (200 or more), northwestern China (160 or more), and south-central China (about 120). A band of low Q_μ (40-60) separates the maximum in northwestern China from the maximum in north-central China. Our models indicate that Q_μ decreases with depth in eastern China and increases with depth in western China throughout the upper 30 km of the crust.

Q_μ at all depths is lower everywhere in southern Asia than it is in stable regions of the world, but not as low as in much of Iran and Turkey. Differences in the depth distribution of Q throughout this region, as well as those found earlier in the Middle East, suggest that discriminants will not be transportable unless they have been corrected for regional and depth variations in Q.

KEY WORDS: attenuation, Q, fundamental-mode surface waves, multi-mode surface waves

OBJECTIVE

The overall objective of this research is to map regional variations of surface-wave attenuation throughout the Tethysides belt of southern Asia (Sengör, 1987) in as much detail as possible and to determine models of seismic Q that explain those variations in attenuation. When our maps are completed we plan to determine how regional variations of Q_μ and its depth distribution will affect the propagation of regional phases. Some practical questions that we will address are the extent to which those Q_μ variations will affect magnitude determinations and the transportability of discriminants using regional phases.

RESEARCH ACCOMPLISHED

We have determined Rayleigh-wave attenuation coefficients (γ_R) corresponding to 51 paths in nine sub-regions of southern Asia using a standard two-station method and have inverted those values for Q_μ structure of the crust and uppermost mantle. We have also obtained three-layer models of Q_μ, between depths of 0 and 60 km, for 25 different paths between single events and single stations using Rayleigh waves and a multi-mode method that matches observed to computed multi-mode amplitude spectra (Cheng and Mitchell, 1981; Cong and Mitchell, 1998). The two-station method, while it allows us to invert for multi-layered models, suffers from poor areal coverage and the data sometimes exhibit effects of focusing or defocusing. The single-station method, while providing simpler Q_μ models, provides better areal coverage and is less affected by focusing/defocusing. We have therefore used the single-station method to construct contour maps of Q_μ variation in three layers.

We will emphasize single-station results in this paper, but will compare models obtained from single-station observations with those obtained from the inversion of two-station attenuation coefficient data. Suffice it to say that we obtained attenuation coefficient values for the fundamental Rayleigh mode by measuring spectral amplitudes over periods between about 5 and 100 seconds, and correcting them for the effect of wave spreading. We then inverted those attenuation coefficient values to obtain models of Q_μ for nine regions of China.

Figure 1 shows the locations of the single-station paths used in this study. We attempted to restrict all paths to being completely continental, so as to avoid well-known adverse effects encountered when surface waves traverse continental margins. Figure 1 indicates that, with only one exception, we were able to do that. The path coverage is sufficiently great that we can develop maps of Q_μ variations at different depths. We decided to use three layers, the first being 10 km in thickness, the second being 20 km in thickness, and the third being 30 km in thickness. The total span of thickness (60 km) is similar to the largest crustal thickness known in the region (the Tibetan Plateau). The increasing layer thickness with depth reflects the fact that our ability to resolve detail decreases with increasing depth.

The single-station method entails the measurement of spectral amplitudes for the fundamental Rayleigh mode between periods of about 5 s and 80 s and of the superposition of higher Rayleigh modes at periods between about 3 and 10 s. Theoretical spectra are computed for an assumed velocity model, a known earthquake focal mechanism, and various crustal models of Q_μ. The Q_μ model is changed until the theoretical spectra the model produces, exhibits the same levels and shapes as the observed spectra. Examples, from a recording at station XAN, appear in Figure 2. Both examples use observed spectra for a recording at station XAN. The upper example compares those spectra with theoretical spectra obtained using the Q_μ model obtained from the inversion of fundamental-mode Rayleigh-wave attenuation data obtained using the two-station method in region 2 in southeastern China. The lower example compares the same observed spectra to theoretical spectra for a three-layer model. Figure 3 shows that the two models are very similar throughout the upper 60 km of the crust and mantle.

It is not possible to obtain such good agreement in all cases. Figure 4 shows a comparison of models obtained using the two-station and single-station methods in the northeastern-most portion of our study area (southeastern Siberia). The upper 20 km of the models exhibit excellent agreement but the model obtained using the two-station method (group 6) exhibits a zone of very high Q_μ at depths between about 20 and 45 km depths. We believe that the anomalously high values are due to focusing of Rayleigh-wave energy at longer periods for the more distant station in the two-station method. The focusing is likely due to lateral variations in velocity structure in the region.

Figures 5-7 present preliminary maps of Q_μ variation at three depths beneath southern Asia. Figure 5 indicates that for layer 1 (10 km thick) Q_μ is highest in southeastern China, where it reaches about 250, and could be higher further to the east if we had data coverage for that region. The high values in this regions, relative to surrounding regions, are consistent with the variations of Lg coda Q in Eurasia found by Mitchell et al. (1997). Q_μ decreases from east to west and reaches a minimum of about 40 in parts of western China, including part of the Tibetan Plateau. Further to the west Q_μ increases in a region that comprises the Tarim Basin and parts of southwestern China.

Figure 6 shows the variations of Q_μ in layer 2 (20 km thick). Those values are also highest in eastern China (as high as about 140) and are lowest in the eastern part of the Tibetan Plateau (about 60) and in the southern-most part of central China (about 80). Between the two regions of low Q_μ a band of relatively high values (with maximum values of about 140) extends northward to Mongolia. North of the China-Mongolia border a region of low Q_μ (60-80) lies within the broader band of high values.

Figure 7 shows the variations of Q_μ in layer 3 (30 km thick). This layer contains a concentrated zone of high Q_μ values (as large as 200) in north-central China and another concentration of high values (up to 160) in northwestern China. The two regions of high Q_μ are separated by a north-south trending band of low Q_μ values (40-60). Eastward from the high values in central China, Q_μ decreases, first rapidly then gradually, to about 100 throughout eastern China.

In eastern China, Q_μ appears to decrease with depth through the upper 30 km of the crust (layers 1 and 2) while in western China it appears to increase with depth. A zone in which Q_μ stays relatively constant with depth separates the two regions.

Q_μ throughout our region of study was determined using Rayleigh-wave attenuation at periods between about 5 and 80 s. The values that we found are low (40-200) compared to those found at those periods in many stable regions of the world (about 300-1000) in earlier studies (see Mitchell, 1995). They are, however, not as low as those found in the upper 30 km of the crust in the Iran/Turkey Plateaus (50-70), a region of active plate collision (Cong and Mitchell, 1998).

CONCLUSIONS AND RECOMMENDATIONS

Our analysis of single-station multi-mode propagation in southern Asia indicates that Q_μ varies systematically in an east-west direction across China. The overall trend going from east to west is a relatively large decrease in Q_μ in the uppermost 10 km of the crust and a smaller decrease in the underlying 20 km of the crust. These trends lead to models in which Q_μ in the eastern part of China that decrease with depth and in the western part of China that increase with depth. These differences suggest that discriminants based upon amplitude ratios of phases that traverse the deep crust or upper mantle (such as Pn) to those that traverse the upper crust (such as Pg), or average the entire crust (such as Lg), will not be transportable unless the phases are corrected for different Q distributions.

It will be important to improve data coverage throughout this entire region so that regional variations of Q_μ and their distribution with depth can be mapped in greater detail. We should also determine the effect that variations in the depth distribution of Q_μ will have on various regional phases that might be used in proposed discrimination schemes.

ACKNOWLEDGEMENTS

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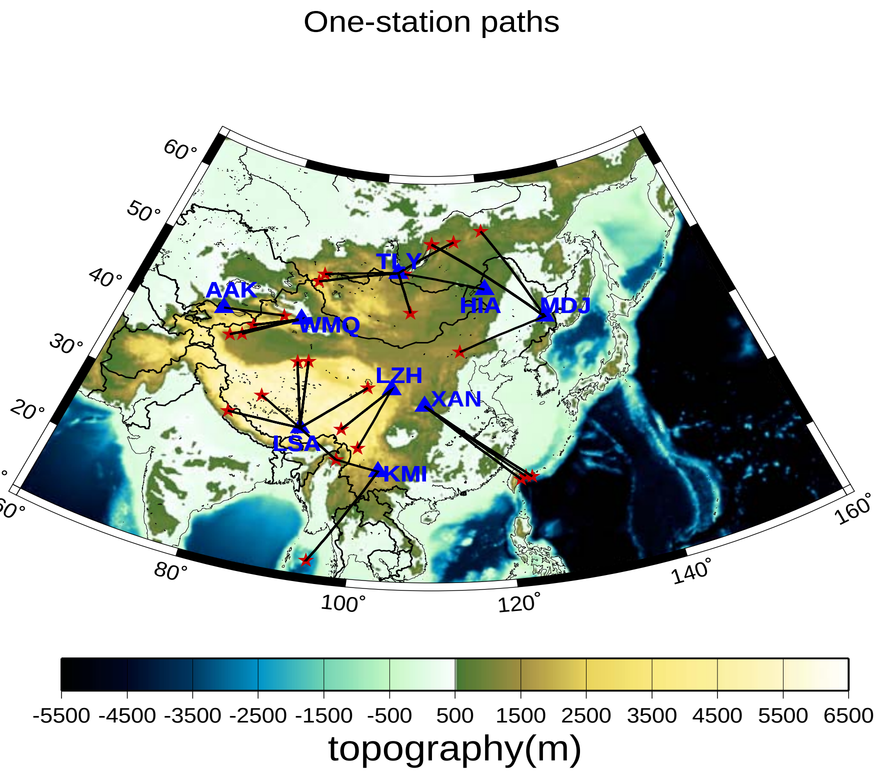
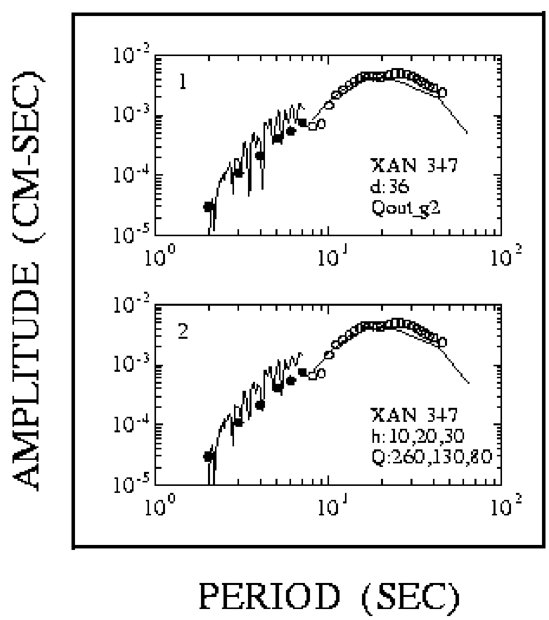


Figure 1. Map of single-station paths used in this study. Stars denote earthquake epicenters and triangles denote seismic stations.

Figure 2. Examples of observed and theoretical amplitude spectra. Open circles indicate amplitude spectra of fundamental-mode Rayleigh waves and closed circles indicate amplitude spectra of the composite of higher modes at periods between 2 and 8 seconds. The upper example compares observed spectra at station XAN with theoretical spectra for a model obtained from the inversion of fundamental-mode Rayleigh-wave attenuation coefficient data using the two-station method. The lower example compares the same observed spectra with theoretical spectra for a three-layered Q model in the same region.



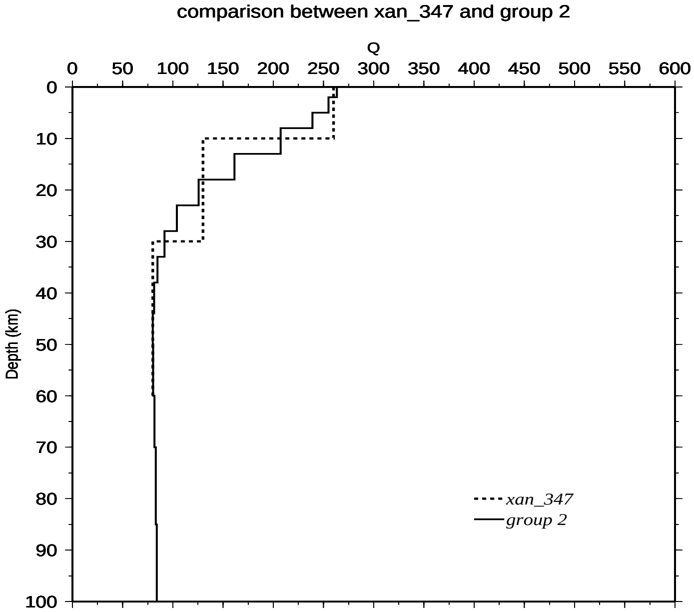


Figure 3. Shear-wave Q models obtained from the inversion of two-station attenuation coefficient data (solid line) and from trial-and-error matching of observed and theoretical multi-mode spectra (dashed line).

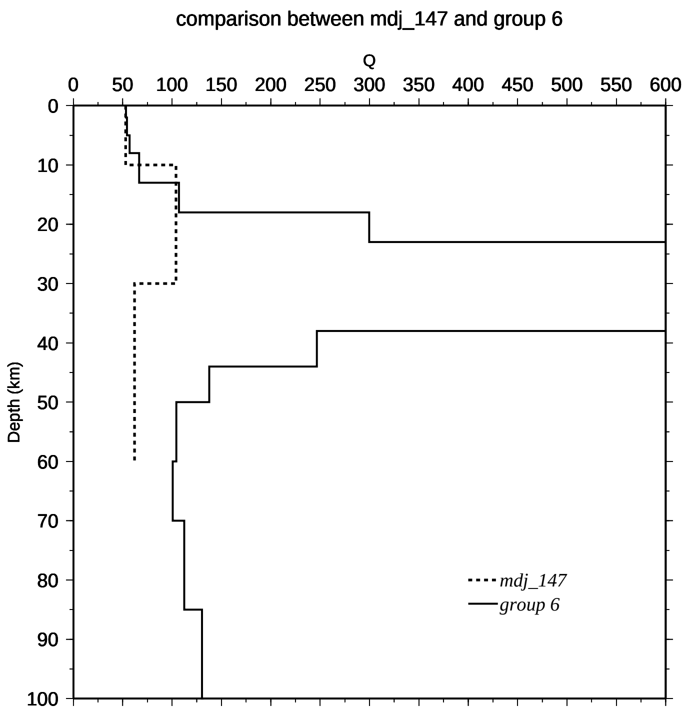


Figure 4. Comparison of models obtained using the two-station method (solid line) and the single-station method (dashed line) for the northeastern-most portion of our map (southeastern Siberia). The anomalous high-Q layer centered at about 30 km is likely due to contamination of the two-station attenuation coefficient data by focusing at the distant station.

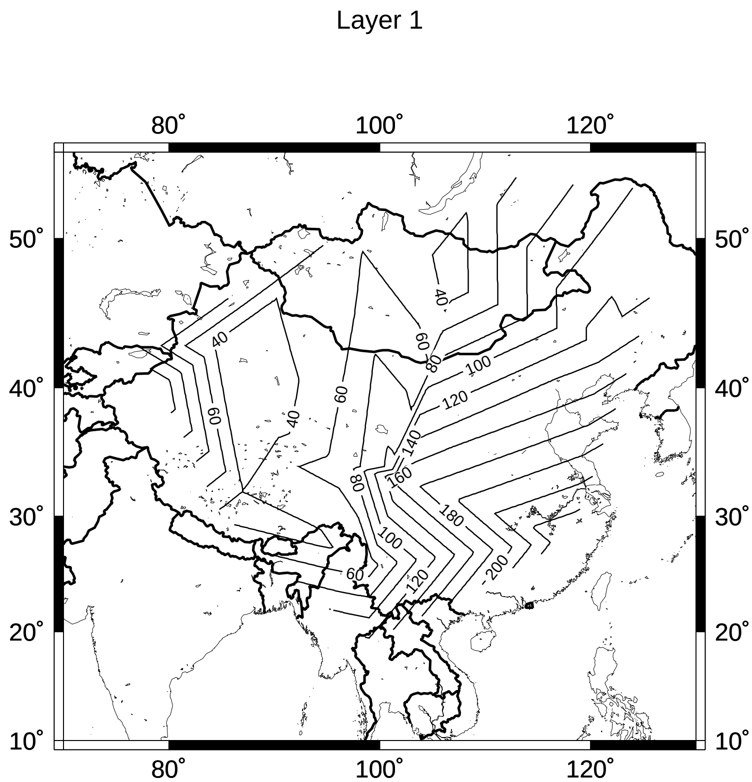


Figure 5. Contour map of shear-wave Q variation in the upper 10 km of the crust (layer 1) in the region of study. The contour interval for Q is 20.

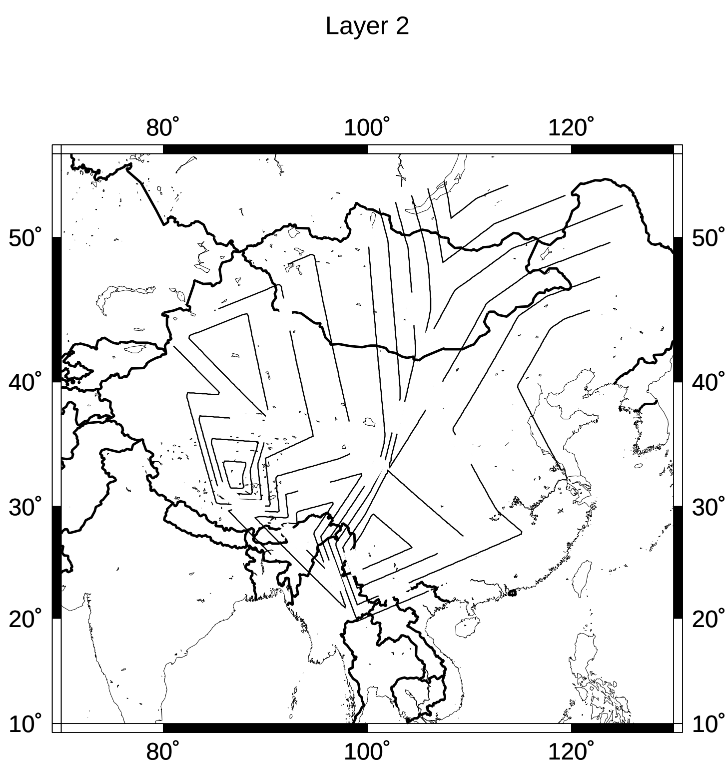


Figure 6. Contour map of shear-wave Q variation in the depth range 10-30 km in the crust (layer 2). The contour interval for Q is 20 km.

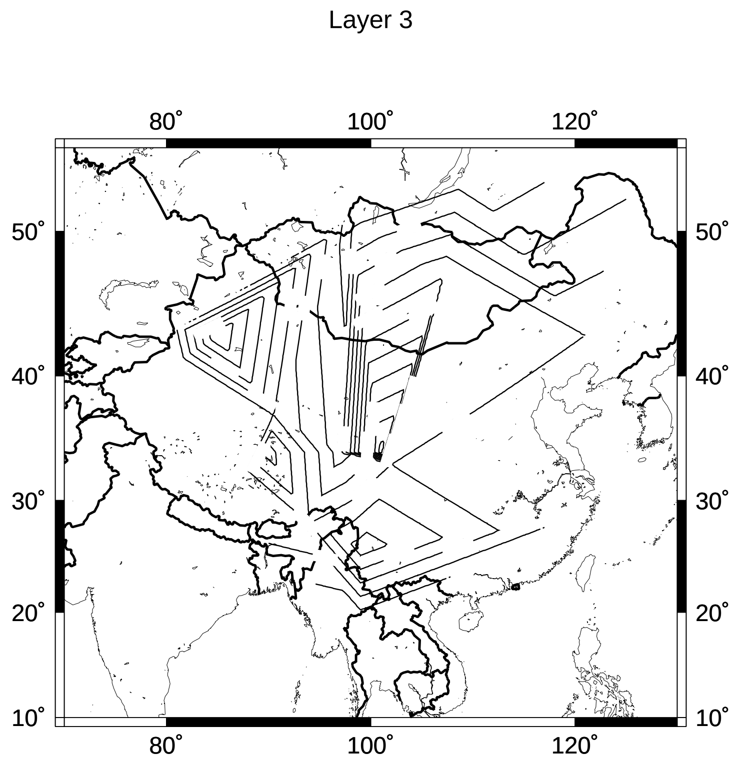


Figure 7. Contour map of shear-wave Q variation in the depth range 30-60 km (layer 3). The contour interval for Q is 20.